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Post-Launch Support for DMSP SSIES Sensors

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14. ABSTRACT
This report summarizes activities related to the support of immediate post-launch activities related to the evaluation of sensor performance for the Special Sensor for Ions, Electrons, and Scintillation (SSIES) that is flown on the the Defense Meteorological Satellite Program (DMSP). The thermal plasma sensors that constitute the SSIES instrument complement provide measurements that describe the composition, velocity, and temperature of the ions and electrons. Each sensor has operational variables that may be adjusted to optimize the sensor performance. In addition, the ground software must be adjusted to accommodate the prevailing environmental conditions that can change dramatically during a solar cycle. Here, we describe support activities following the launch of each SSIES sensor that were undertaken to evaluate the sensor performance and optimize the subsequent routine operations.

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Ionosphere, Electrodynamics, Satellite, Sensors

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1. INTRODUCTION

With support from this contract we address the fundamental need to maintain and produce a high quality data stream that is of value for specification of the geospace environment. This task is accomplished through 4 basic activities that are undertaken in collaboration with scientists at the Air Force Research Laboratory (AFRL) and the Air Force Weather Agency (AFWA). Immediately following the launch of Special Sensors Ions Electrons and Scintillations (SSIES) a verification of the sensor performance is undertaken by inspection of data that is expressly provided by scientists at AFRL. Following initial data evaluation we are provided routine access to the Defense Meteorological Satellite Program (DMSP) SSIES data through the delivery of CD data disks to the University of Texas at Dallas (UTD) from AFRL. This data is used to continuously monitor the instrument performance during the entire mission life. In addition to the sensor/payload performance we also monitor the ground software performance. This is accomplished by running data reduction procedures at UTD that emulate those conducted by scientists at AFRL and AFWA. Finally, we also undertake the construction of improvements to the ground software that allow the most efficient specification of the geospace environment and the use of data in collaborative science activities with AFRL. All these tasks are described in more detail below.

2. INSTRUMENT PERFORMANCE ANOMALIES

Over the course of operations of the SSIES sensors on F11, F12, F13, F15, and F16 several performance anomalies have been identified, and work-arounds and/or corrections have been implemented in flight software, ground software, and instrument operations.

2.1. Aperture Bias Control

The solar array for the DMSP satellites cell interconnects that are exposed to the ambient plasma environment and positively biased with respect to the plasma. The preferential collection of thermal electrons by these surfaces is counterbalanced by a spacecraft ground reference that is driven correspondingly negative with respect to the plasma. Thermal plasma sensors cannot function optimally unless their reference ground is close to the plasma potential and thus the SSIES sensors incorporate circuitry (called SENPOT) to bias the sensor reference ground with respect to the spacecraft ground.

Following the launch of the F14 satellite the SENPOT circuitry was found to function sporadically. An analysis of the periodic malfunction lead to a hypothesis that grounded conductive covering on the thermal blanket was sporadically allowed to contact the rear face of the SSIES ground plane. Since the SENPOT requires that this surface be biased with respect to spacecraft ground, this action would render the circuit inoperable.

Following this problem, special pre-launch inspection of the thermal blanket in the neighborhood of the SSIES aperture plane is conducted to insure that contact between the conducting surfaces is not possible.

2.2. Performance in H+ Rich Environments

The DMSP satellites orbit near 840-km altitude where the random thermal velocity of H+ ions is comparable to the satellite velocity. In such circumstances, angle of arrival measurements from the Ion Drift Meter (IDM) may be significantly compromised. First, the sensitivity of the IDM is significantly reduced but more importantly, the ambient plasma stream can be easily disturbed by the conducting surfaces on the spacecraft that are at high negative potentials with respect to the plasma. Employing a repeller potential to reject light ions prior to the collimating aperture of the IDM can mitigate this problem. In regions where H+ is the dominant ion, it is necessary to recognize that the estimate of total ion concentration from the sensor will now be compromised by the omission of this constituent specie. By examining that data from the Retarding Potential Analyzer (RPA), it is possible to locate regions where H+ is significant, to verify that the application of a repeller bias to remove the H+ signal from the IDM is appropriate, and to flag the operations so that total ion concentration measurements from the IDM are not used in scientific or operational applications.

During the initial operations of the DMSP satellites, an inter-calibration of the sensors that measure the total ion (electron) concentration is undertaken. The RPA, the IDM, the scintillation meter (SM), and the Langmuir probe (LP) all have this capability and we determine the relative performance of these devices throughout several orbits. We find that in environments where H+ remains less than 5% of t he total ion concentration, then estimates of the total ion concentration from all devices are the same. In the presence of larger H+ concentrations we find deviations from total ion concentration estimates that differ among the RPA, SM, and LP. The differences between RPA and LP may be reconciled by recognizing that a true saturation current from thermal electrons is never achieved within the usually used retarding voltages. However, differences between the RPA and SM are not easily reconciled. We believe that such differences are due to the trajectories of H+ ions that are disturbed by biased surfaces on the spacecraft that are adjacent to, and in some cases in front of, the sensor apertures. While extensive knowledge of the surface configuration of the satellite is not incorporated into our analysis, we conclude that the RPA provides the most reliable estimates of total ion concentration by noting the rate of change of Ni as a function of solar zenith angle and composition.

2.3. Effetcs of High-Energy Particle Impacts and Single Event Upsets

The SSIES-3 sensor suite incorporated a newly designed main electronics package to accommodate revised instrument functions and on-board processing. The main electronics package was supplied as a subcontract to UTD through Sanders Corporation and while every effort was made to utilize radiation hardened and appropriately screened parts, all evidence suggests that the microprocessor was subject to single-event upsets produced by high-energy particle impacts. Analysis of initial events indicates that the events occur in regions where high-energy particles might be present. It was also discovered that a command "reset" would re-enable the sensor functions. Due to the long storage time of the sensors, it was not deemed practical to reconvene the original design team and program an uploadable patch that would rectify the situation. Rather, the

ground command sequences were reprogrammed to execute the "reset" command during the equatorial crossings of every orbit. This command-level fix produces small data outages when a single-event upset is experienced, but provides an automatic way to re-establish the instrument functionality.

3. GROUND SOFTWARE PERFORMANCE ANOMALIES

During this contract period, the DMSP satellites have sampled the topside ionosphere through an entire solar cycle. During this period, the ionospheric composition at middle latitudes can change from dominantly O+ to dominantly H+ and at high latitudes the wintertime ion number densities can be as low as 10^3 cm^{-3}. We have found that the originally configured software for least-squares analysis of RPA characteristics does not function optimally through this range of conditions without amendments to algorithms.

In H+ dominant regions it is not sensible to retrieve the ram ion drift and the aperture plane potential. It is straightforward to recognize such cases and amend the least-squares fitting procedure. However, as the fraction of light ions decreases, a transition to an analysis procedure that includes the extraction of the ram velocity and the aperture plane potential must be made. This transition can be problematic since a substitution of He+ fro H+ can be affected with appropriate values for the ram drift and ion temperature. It is thus necessary to detect erroneous solutions and to constrain the analysis procedure in a second attempt to retrieve the appropriate solution set. This approach has been significantly tested during the DMSP mission lifetimes and now functions with a reasonable degree of reliability. It allows a continuous evaluation of the flight data and also the generation of quality flags that will be of use when utilizing the data for scientific and operational purposes.

4. GROUND SOFTWARE DEVELOPMENT ACTIVITIES

The transition from the SSIES-2 hardware configuration prior to F16 to the SSIES-3 hardware configuration from F16 forward required that the initial data evaluation procedures and the ground software procedures be modified. For the SSIES hardware, the drift meter function was changed to replace a normal rezero and offset procedure to a simpler periodic input inversion process. In this way, rather than a computation of the absolute ion arrival angle at all times, an offset is derived at each inversion and continuously carried forward into the arrival angle determination. This procedure decreases the switching transients in the data stream leading to a more continuous reliable data stream. The function of the RPA was also changed in the SSIES-3 hardware. In this case a 4-second sweep produced by micro-stepping the retarding potential is replaced by a discrete step retarding potential sequence that occupies 1 second. This approach significantly reduces the impact of spatial gradients on the sweep and produces higher fidelity measurements with smaller statistical errors. Finally the on-board analysis procedures were changed to include computation of the ion temperature and ram velocity.

All these changes necessitated a reformatting of the existing telemetry stream and concomitant changes in the ground software to evaluate the instrument performance. During the course of the software development activities a continuous effort to ensure the reproducibility of data sets produced at UTD and AFRL was undertaken. The exchange

of algorithm descriptions and data files allows this to occur in a reasonably seamless fashion and for collaborations between scientists at each institution to be undertaken most efficiently.

5. COLLABORATIVE SCIENTIFIC ANALYSIS

With the continued update of the ground software and associated geophysical data sets it is possible and necessary to carry out calibration and validation activities and to develop the machinery that will allow these data sets be used in an operational environment. In this regard we were able to support the conduct of two major initiatives.

5.1. Plasma Parameters

The DMSP spacecraft produces global distributions each day of the key thermal plasma state-variables as it traverses through different longitudes and two discrete local times. The topside ion number density, ion and electron temperature, and plasma velocity for which the longitude variations can be examined may be compared at specific locations with ground-based measurements. Figure 1 shows the ion number density as a function of magnetic latitude for a period of 5 days in July 2002. The measurements are shown for the dayside crossing of the magnetic equator near 0900 local time. Repeatable longitudinal variations are seen each day.

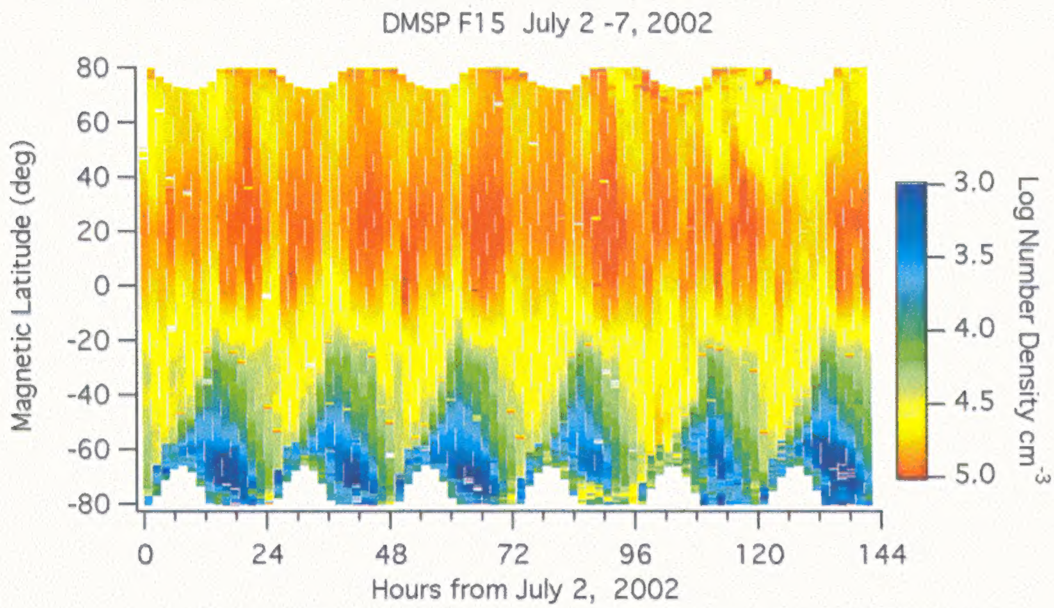

Figure 1. Ion number density variations measured by DMSP F15.

Toward the end of the time period, density enhancements are seen at northern high latitudes associated with enhanced levels of magnetic activity. Data such as these allow continuous assessment of the instrument performance and comparison with ground-based measurements when the satellite intersects a common volume sampled by incoherent scatter radar. We have continually refined data visualization techniques to facilitate the calibration and validation of the SSIES data.

5.2. Electrostatic Potential Variations

The polar cap potential difference is a parameter that is frequently used to describe the global distribution of potential across the high-latitude ionosphere. It provides a fundamental input driver for ionospheric and magnetospheric specification and, as such, efforts to maintain a robust measure of the cross cap potential were undertaken during the conduct of this contract. There are two major problems that must be consistently considered. First, the specification of a potential distribution requires a quasi-steady state to exist during the satellite pass that occupies about 30 minutes in universal time. Second, the spatial extent of the region influenced by the high-latitude convection pattern must be specified. These two conditions frequently conflict since a time variation can lead to a residual potential that could be identified as an extension of the auroral flow. To date, the automatic algorithms that construct the polar cap potential use a canonical value for the equatorial limits to anchor the potential at zero. Figure 2 shows the vertical and horizontal ion drift (top panels) and the electrostatic potential distribution (bottom panel) determined from a northern hemisphere pass of the F13 satellite in June 2001. The potential is derived using a model magnetic field to compute the electric field along the satellite track that is subsequently integrated as a function of distance.

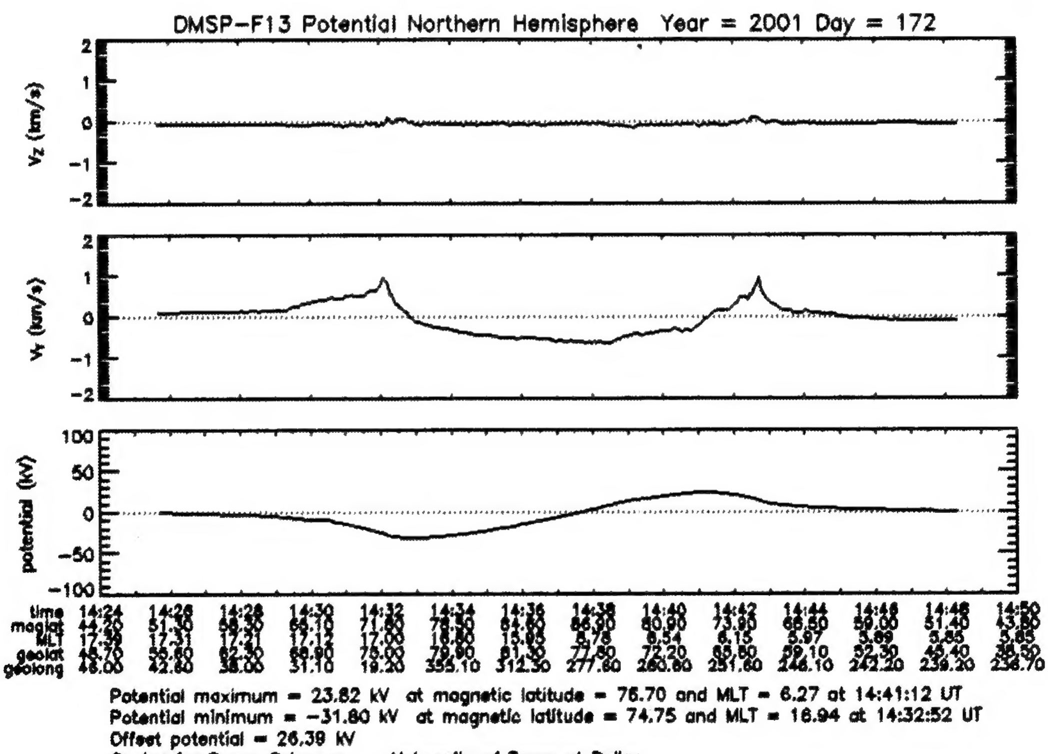

Figure 2. Ion drift and electric potential derived from DMSP F13 data.

The textual data at the bottom of this plot shows the information typically delivered to models of the magnetosphere and the ionosphere-thermosphere. In this case, we note that the total cross polar cap potential drop is about 55 kV. However, note that the adjusted potential distribution required an offset of about 26 kV to be removed between end-points

located at 50-degrees magnetic latitude in the morning and evening sides. Examination of the zonal ion drift (middle panel) shows that a residual westward (positive Vy) flow is quite apparent at latitudes below the auroral flow in the evening sector. Similarly, there is a residual westward (negative Vy) flow in the low-latitude morning sector. Even small flows such as seen here will lead to quite large cumulative errors in the calculated potential. Upon inspection, we can verify that removal of this offset is probably appropriate. However, further work is required to produce an automatic algorithm to assess the uncertainty of the potential derived in this way.

6. CONCLUSION

Post-launch support for the SSIES instrumentation of the DMSP satellites has led to continuous improvement to the instrument operational modes, to the ground software producing geophysical parameters, and to the data visualization procedures used to calibration and validation of the instruments. We expect that continued activity of this kind to encompass support of the SSIES instruments on DMSP F17-F20 will result in similar advances. Ultimately, this activity will lead to definition of instrumentation and approaches to data reduction that will provide reliable space weather specification for a next generation satellite program.